On Integrating Artificial Intelligence and Decision Analysis Technologies: Determ Supp Req for a Combat Force

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13. ABSTRACT (*Maximum 200 words*)

As part of this project, two related research issues were investigated. The first of these involved the analysis of the support requirements planning problem and the development of a collection of mathematical programming models of the task. Following this work, the need for a general purpose distributed decision support environment was identified. The environment was needed in order to facilitate the development and deployment of decision support resources such as mathematical models by a dispersed group of developers over a network in such a manner that they could be accessed by a distributed group of users. This led to our work on DecisionNet, a world wide web-based distributed decision support environment. DecisionNet uses intelligent agents to provide mediated, interoperable access to mathematical model-based decision support tools. The DecisionNet prototype is available at http://www.heinz.cmu.edu/project/dnet.

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1. Statement of the Problem

This project investigated two problems. The first concerned the study of the support requirement planning problem. The support requirement planning problem is encountered in military logistics planning and consists of determining the set of combat support and combat service support units which are required to sustain a combat force. We formulated this problem under a variety of information availability assumptions as variants of set covering and goal programming models (Rardin, 1997). These are described in more detail in Section 2. The second problem we studied concerned making models such as those that we had formulated for the support requirement planning problem available in distributed web-based environment. We developed and implemented a virtual decision support system repository – DecisionNet -- using the metaphor of an electronic market in response to this problem. Software agents referred to as brokers are a key component of DecisionNet. The brokers permit users to discover, script and use mathematical models and decision support tools made available by providers on remote servers. Broker functionality is enabled through the use of meta information about the resources in the repository obtained during registration from providers. DecisionNet is available online at http://www.heinz.cmu.edu/project/dnet.

2. Key results

In this section, we summarize the key results of our work. Since the work on DecisionNet is well documented in the attached set of publications, in this section we will elaborate on our work on support requirements planning. Following this discussion, we will briefly summarize the results of our work on DecisionNet.

2.1 Support Requirements Planning: Key results

As noted above, support requirements planning consists of determining the set of combat support and combat service support units which are required to sustain a combat force. The set of combinatorial optimization models we formulated to solve this problem represent the key results. Conceptually, each model attempted to solve a "supply and demand" matching problem with varying degrees of sophistication. Since combat forces impose *demands* for various services and combat support and service support units *supply* the capabilities required to provide these services, planning involves matching the supply capabilities with demand requirements. Evaluating alternative plans can be done in several ways of which we considered two. The first approach is to determine the *minimum number* of combat support and service support units assuming the supply and demand constraints to be hard constraints. This is a variant of the set covering problem. The alternative approach is to treat the supply and demand constraints as soft constraints and to determine the number of combat support and combat service support units that need to be added to the force to *minimize deviations* in the supply and demand constraints. This is a variant of a goal programming problem. The innovative feature of the formulation is the treatment of the constraints in the problem as both hard and soft constraints and inclusion of the violations of the soft constraints as goals to be minimized in the objective function. In an environment where most support plans are inherently infeasible, the model seeks out plans that violate as few soft constraints as possible. Two models are presented to illustrate the approach.

Model 1: A Set Covering Formulation

Problem Statement: Assume that there are a set of spatially distinct zones in which combat units and support units can be deployed. Given information both about the demands that a support unit can service in the zone in which it is deployed and in other zones, and information about the demands imposed by combat units in each zone, determine the minimum number of support units that should be deployed and the zone in which they should be deployed. We note that this type of problem specification is appropriate in "near real time" support requirements planning scenarios in which data about spatial deployment of forces is available.

Mathematical Formulation:

$$Min \sum_{i \in CS \cup CSS} \sum_{z \in Zones} X_{iz}$$

$$s.t$$

$$\sum_{i \in CS \cup CSS} \sum_{z_1 \in Zones} C_{ijz_1z_2} - ID_{ijz_1z_2} \geq D_{jz_2} \forall j \in Demands$$

$$\forall z_1 \in \text{Zones}, \forall z_2 \in \text{Zones}$$

$$\sum_{z \in Zones} X_{iz} = 1 \quad \forall i \in CS \cup CSS$$

$$X_{iz} = 0 \; or \; 1$$

X_{iz} is a binary variable which is designed to model the deployment of unit **i** in zone **z**. It takes on a value of 1 if the unit is deployed and takes on a value of 0 if the unit is not deployed.

$C_{ijz_1z_2}$ is a parameter which models the amount of demand type **j** that arises in zone **z2** which can be met by unit **i** in zone **z1**.

$ID_{ijz_1z_2}$ is a parameter which models the amount of demand **j** that is imposed in zone **z2** by unit **i** in zone **z1**. Note that zone **z2** can be the same as zone **z1**.

Zones is a set of spatially distinct zones in which combat and support units may be deployed. It is assumed that the zone in which each combat unit is deployed is known.

CS is the set of combat support units from which units are selected.

CSS is the set of combat service support units from which units are selected.

Demands is the set consisting of the types of demands that are imposed by combat units.

Model 2: A Goal Programming variant

Problem Statement: This is similar to model 1 in terms of the level of complexity incorporated into the problem. In addition to imposed demand, the specification assumes the existence of zones in a battlefield. Given information about combat units, the zones in which they are deployed and data about the zones in which demands for service arise, the problem is to determine which support unit should be included in the force and zone in which it should be deployed. As noted in our description of model 1, this type of problem specification is appropriate in "near real time" support requirements planning scenarios in which data about spatial deployment of forces is available.

Mathematical Formulation:

$$\text{Min} \sum_{j \in Demands} \sum_{z \in Zones} P_{jz} s^-_{jz} + Q_1 d^+_1$$

$s.t.$

$$\sum_{i \in CS \cup CSS} \sum_{z_1 \in Zones} C_{ijz_1z_2} \mathbf{X}_{iz_1} - ID_{ijz_1z_2} - s^+_{jz_2} + s^-_{jz_2} = D_{jz_2} \; \forall j \in Demands, \; \forall z_2 \in Zones$$

$$\sum_{i \in CS \cup CSS} \sum_{z \in Zones} X_{iz} - d^+_1 + d^-_1 = 0$$

$$\sum_{z \in Zones} X_{iz} = 1 \; \forall i \in CS \cup CSS$$

$$X_{iz} = 0 \; or \; 1$$

$\mathbf{X_{iz}}$ is a binary variable which is designed to model the deployment of unit **i** in zone **z**. It takes on a value of 1 if the unit is deployed and takes on a value of 0 if the unit is not deployed.

$C_{ijz_1z_2}$ is a parameter which models the amount of demand type **j** that arises in zone **z2** which can be met by unit **i** in zone **z1**.

$ID_{ijz_1z_2}$ is a parameter which models the amount of demand **j** that is imposed in zone **z2** by unit **i** in zone **z1**. Note that zone **z2** can be same as zone **z1**.

d^+_1 is the slack variable which models the number of support units that are added to the force.

d^-_1 is the slack variable which plays the role of a dummy variable in this formulation.

$s^+_{jz_2}$ is the slack variable which models the deviation over and above required demand.

$s_{jz_2}^{-}$ is the slack variable which models the amount by which supply falls short of required demand.

Zones is a set of spatially distinct zones in which combat and support units may be deployed. It is assumed that the zone in which each combat unit is deployed is known.

CS is the set of combat support units from which units are selected.

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Demands is the set consisting of the types of demands that are imposed by combat units.

Data Requirements

In order to use the supply and demand models, several important data requirements must be met. We divide the data needs into two broad categories: data describing demands imposed by a force in combat, and data describing the capabilities of Army units. Each category of data must be represented in compatible units, such as tons, gallons, hours, miles, etc. Fortunately, there is a "status quo" approach to this that is in regular use today and can be used to test the supply and demand model.

To project future demand for resources in combat, the Army relies primarily on planning factors, such as those contained in FM 101-10-2. In addition, there are software programs (SURE - Supply Usage Requirements Estimator, and KBLPS - Knowledge Based Logistical Planning System) that use planning factors and other sources to determine gross estimates of demands. Finally, demand is sometimes estimated through simulation, based on assumptions about the threat, host nation support, and many other factors.

The capabilities of Army units is expressed, by SRC, in Section I of the Tables of Operations and Equipment (TOE). This data exists electronically as part of the TRADOC Documentation System. As a hypothetical example, the TOE might say that a light transportation company at a 75 percent availability rate can make four round trips per day in order to move a total of 1000 short tons. Similar data is available for other key support SRCs.

To summarize, we worked closely with Major Branley who was then with the US Army Artificial Intelligence center to ensure the usability of the models that were developed as part of this study.

2.2 Distributed Decision Support Environment

We investigated three issues in the context of creating a distributed, web-based, virtual repository of decision support tools.

a. Given that our decision support resources were based on mathematical models, we developed a formal framework to address model representation and associated operations (e.g., model linking) in the repository. The formal framework was developed first order logic and used to analyze the semantics of a typed modeling language called Ascend (Piela, 1989). Ascend is an example of modeling language that can be used to represent models in a DecisionNet repository. The details of our formal framework are described in the paper, "On Formal Semantics and Analysis of Typed Modeling Languages," forthcoming in the *INFORMS Journal on Computing*.

b. A key feature of the environment is to enable users to employ the services of brokers to discover and execute -- in a seamless and interoperable manner -- decision support resources on remote servers. To accomplish this without requiring providers of resources to be experts in web technology, we designed brokers that could create custom "wrappers" for existing decision support resources using meta information about these resources. The key results here were the definition of a new transaction model and the development of representation for the types of meta information required to enable the functionality displayed by the brokers. The paper, "Decision Support on Demand: On Emerging Electronic Markets for Decision Technologies," forthcoming in *Decision Support Systems* and all the conference publications listed below elaborate on this topic. An application of the core technology developed as part of DecisionNet was applied to the domain of data quality assessment. This work is described in the paper titled "Accounting Information System Data Quality Assessment: A DSS Approach."

c. Given the rapid growth in electronic commerce and the possibility that the sort of environment we have proposed and developed could facilitate "pay per use" of decision support applications, we analyzed DecisionNet from an electronic commerce perspective. This work is described in the paper, "Electronic Commerce in Decision Technologies: A Business Cycle Analysis," published in the International Journal of Electronic Commerce.

3. List of Publications

3.1 List of Publications in Journals

D. Kaplan, R. Krishnan, R. Padman, J. Peters, "Accounting Information System Data Quality Assessment: A DSS Approach," Communications of the ACM, pp. 72-78, February 1998.

H. Bhargava, R. Krishnan, P. Piela (1997), "On Formal Semantics and Analysis of Typed Modeling Languages," forthcoming in the INFORMS Journal on Computing.

H. Bhargava, R. Krishnan, R. Mueller (1996), "Electronic Commerce in Decision Technologies: A Business Cycle Analysis," International Journal of Electronic Commerce, Vol 1., No. 4, pp. 109-127.

H. Bhargava, R. Krishnan, R. Mueller (1996), "Decision Support on Demand: On Emerging Electronic Markets for Decision Technologies," forthcoming in Decision Support Systems, vol. 19, pp. 193-214.

3.2 List of Publications in Conferences

R. Krishnan, R. Padman, On using Web technologies to architect DSS: The Case of Support Requirements Planning, Proceedings of the ISDSS Conference, pp. 257-280.

H.K. Bhargava, R. Krishnan, S. Roehrig, M. Casey, D. Kaplan, R. Muller (1997) "Model Management in Electronic Markets for Decision Technologies: A Software Agent Approach," Proceedings of Thirtieth Hawaii International Conference on the System Sciences (Winner of the Best Paper award in the Advanced Technology track), pp. 1-11.

H. Bhargava, R. Krishnan, R. Mueller (1995), "On Parametrized Transaction Models for Agents in Electronic Markets for Decision Technologies," Proceedings of the Workshop on Information Technology and Systems, pp. 218-227 (Winner of the Best paper Award at WITS'95).

4, List of Honors/Awards

1. The paper, "Model Management in Electronic Markets for Decision Technologies: A Software Agent Approach," was awarded the **Best Paper** award in the Advanced Technology Track of the Hawaii International Conference on the System Sciences, 1997.

5. Participating Scientific Personnel

1. Ramayya Krishnan, PI
2. Rema Padman, Researcher, Assoc. Professor of Operations and Information Management
3. David Kaplan, Phd Student
4. Nancy Sawan, M.S. Student
5. Paul Varley, M.S. Student

6. Bibliography

1. Ronald Rardin (1977), Optimization in Operations Research, Prentice Hall, NJ
2. P. Piela, R. McKelvey, A. Westerberg (1992), "An Introduction to Ascend: Its Language and Interactive Environment," *Journal of Management Information Systems*, Vol. 9, pp.. 91-121.